Unexploded Ordnance Recovery
Depth Database

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Abstract

When performing site characterization it is important to know the potential depth of penetration of the different Unexploded Ordnance (UXO) items that may be present. Maximum depth of penetration can be calculated by a variety of methods; however, these methods generally use conservative assumptions that overestimate the typical depth of penetration of individual items of UXO. The U.S. Army Engineering and Support Center, Huntsville (USAESCH) has developed a database of recovered UXO items from Formerly Used Defense Sites and Base Realignment and Closure projects. The following are four of the thirteen categories that can be used to sort information from the database:

1. UXO Category (e.g., Projectile, Rocket, Bomb, etc.)
2. UXO Item (e.g., 2.36" Rocket, 500-lb Bomb, etc.)
3. Recovery Depth (Inches) of UXO Item (e.g., 4, 8, 18 inches)
4. Status of UXO Item (e.g., Fired or Buried)

Introduction

Nationwide there are several thousand Formerly Used Defense Sites (FUDS), Base Realignment and Closure (BRAC) and Installation Restoration (IR) projects that have the potential for UXO presence. The U.S. Army Corps of Engineers (USACE) has management responsibility for the environmental restoration projects at all FUDS**.** Currently USACE has approximately 80 active FUDS Ordnance and Explosives (OE) restoration projects. There are no regulatory requirements mandating BRAC and IR installations to use USACE for ordnance restoration; however, approximately 30 of the BRAC and IR installations are using USACE to manage their OE restoration projects.

In the past several years, hundreds of thousands of UXO have been recovered at formerly active and currently active military installations. During this time the penetration nature of the munitions being recovered could not be detailed because no historical data existed relating to penetration. The only option was to use mathematical models to produce a worst case scenario for maximum penetration of the munition. Since the models could only show a worst case scenario, the exact nature of the munition's penetration could not truly be identified. The UXO Recovery Depth Database was developed to obtain a better understanding of the actual nature of munitions being found on the project sites. By gaining understanding about a munitions historical penetration nature, USACE can improve sweep efficiencies, OE Risk calculations, and cost effectiveness. USACE can also use the better understanding to identify the best UXO detection technology to use.

USACE UXO Cleanup Mission

USACE has the primary mission of safely and effectively clearing OE hazards from FUDS properties. The objectives of a FUDS OE response are:

1. Reduce Risk to General Public
2. Ensure Safety of OE Response Specialist
3. Ensure Response is Cost Effective
4. Ensure Compliance with All Applicable Requirements.

Although these objectives are established for work by USACE at FUDS, they are also applied to work performed at BRAC and IR projects. UXO has the potential to be a major public safety hazard; therefore, reducing the risk hazard to the public is a major objective for USACE. Clearing the area of UXO, educating the public about the UXO potential, and/or applying institutional controls can reduce the risk hazard to the public. During the response procedure, the utmost precautions must always be taken to ensure safety to the OE response specialist. USACE OE work is done in accordance with Department of Defense (DoD), Occupational Safety and Health Administration (OSHA), and USACE safety regulations. Using SiteStats, GridStats, UXO Calculator, geophysical mapping and other innovative technologies, USACE provides the information, experience, and capability needed to provide a cost-effective way to restore projects [1]. USACE FUDS projects must be executed in accordance with the requirements set forth in the Comprehensive Environmental Response, Compensation and Liability Act and the National Oil and Hazardous Substance Pollution Contingency Plan.

UXO Recovery Database Description

The UXO Recovery Depth Database includes information from 15 project sites. The database was populated from information found in the final or draft final reports from the projects where UXO had been recovered. The type reports used to obtain data included:

1. Engineering Evaluation/Cost Analysis Reports
2. Removal Action Reports
3. Sampling Reports
4. Site Investigation Reports
5. Time Critical Removal Action Reports.

The current information in the UXO Recovery Depth Database is derived from 18 project reports. The reports were from 11 FUDS and 3 BRAC projects. One set of data is from a BRAC project at Fort Ord, California. The information from Fort Ord was obtained from the onsite database for recovered items.

The UXO Recovery Depth Database includes 9,684 UXO items classified as fired and 6,892 UXO items classified as buried. Each UXO item is entered into the database with information for each of the fields listed in Table 1. Table 1 shows the database fields and an example of a database entry.

Table 1: Example of Database Entry

	Field Name	Example Information
1	Item Number	13213
2	Project Name	Fort Ord
3	Project Location	Monterey, California
4	Project Status	BRAC
5	Excavation Date	01-Dec-98
6	UXO Category	Mortar
7	UXO Item	3" Stokes
8	Recovery Depth (Inches)	8
9	Type of Detector	Schonstedt 52CX
10	Status of UXO Item	Fired
11	Soil Type	Sand
12	Soil Frost Depth (Inches)	0
13	Project Clearance Depth (Inches	48
14	Historical Function of Site	Impact Area/Training Rang

The major categories of the database are the UXO Category, UXO Item, Recovery Depth, and Status of UXO Item fields. Each item is described in the UXO Category field as a Mortar, Rocket, Projectile, etc. The item is then described in the UXO Item field as a specific type of the category, such as 3" Stokes, 2.36", 155mm, etc. The recovery depth of the item is recorded in the Recovery Depth field, and whether it was fired or buried is recorded in the Status of UXO Item field. The other fields are basically as described below:

1. Item Number - An identification number for each item
2. Project Name & Location - Name of the project and its location
3. Project Status – Whether the project is BRAC, FUDS, or IR
4. Excavation Date – The date the item was recovered or excavated
5. Type of Detector – The type of UXO detector used at the project
6. Soil Type - The type of soil occurring at the project
7. Soil Frost Depth – The frost depth in inches
8. Project Clearance Depth - The established clearance depth for project
9. Historical Function of Site - What the site was used for

The database will be an ongoing project that will provide the ability to continually evaluate the process for UXO recovery.

UXO Recovery Depth Analysis

To analyze the data contained in the database, a family of curves was developed to show the number of UXO items found at a certain depth. The actual data were graphed using depth bins of ½ foot increments; for example: 0”, 1” to 6”, 7” to 12”, etc. Due to possible inconsistencies in data collection at project sites some of the graphs had non-monotonic lumps appearing in the curve. To give a more logical fit to the curves and smooth out the non-monotonic lumps, a geometric regression form was used[2]. Figure 1 shows the graph for 40mm projectiles. Shown on the graph are the actual data points at each depth and a regression curve that has been used to show the logical fit of the data. Also shown on the chart is the percentage of UXO found at or less than the specified depth. Figure 1 shows that 50 percent of 40mm Projectiles are found at or less than 6”; 75 percent, 99 percent and 100 percent are at or less than 7”, 24” and 26” respectively.

Figure 1: 40mm Projectile Graph

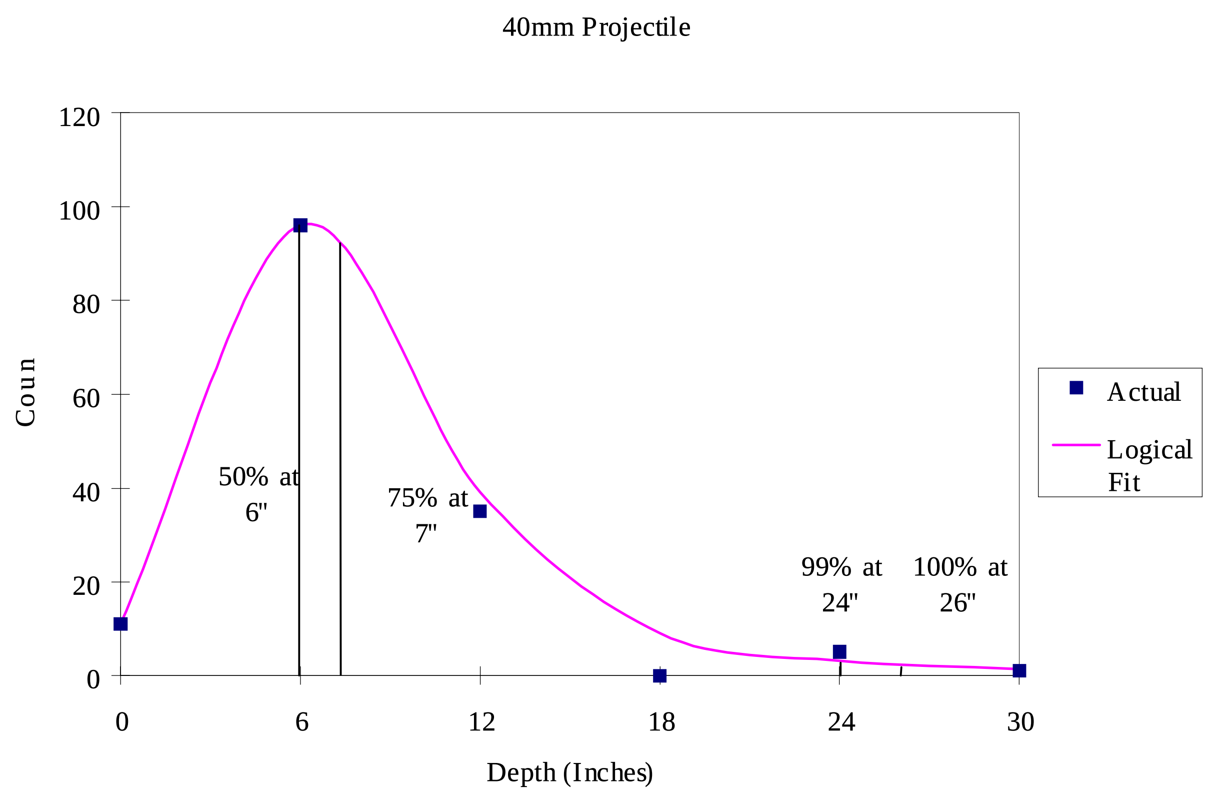


Figure 2, 3, and 4 are the same type of charts for 3” Stokes Mortars, M9 Rifle Grenades, and 35mm M73 Sub-cal Rockets, respectively. These charts provide a better understanding of how deep each UXO item historically penetrates the ground. It can be seen on the four charts that at least 99 percent of the items were found from 0” to 24”. Figure 5 shows the chart for all fired mortars, projectiles, rifle grenades, bombs, rockets, and pyrotechnics. The chart shows that 97 percent of all these items are found at or above 30”.

Figure 2: 3” Stokes Mortars Graph

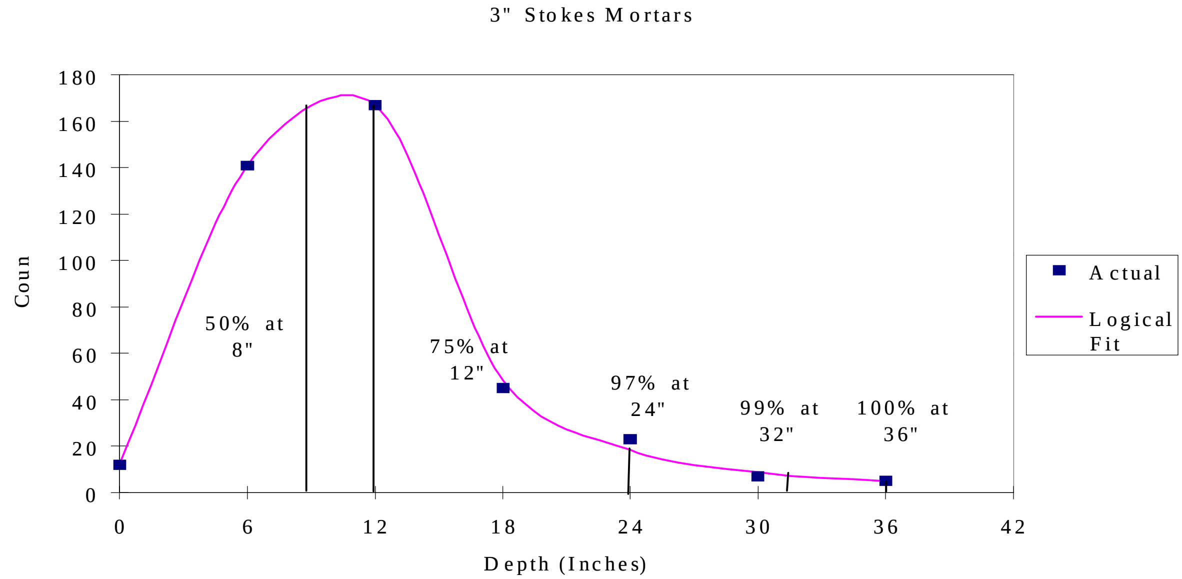


Figure 3: M9 Rifle Grenades Chart

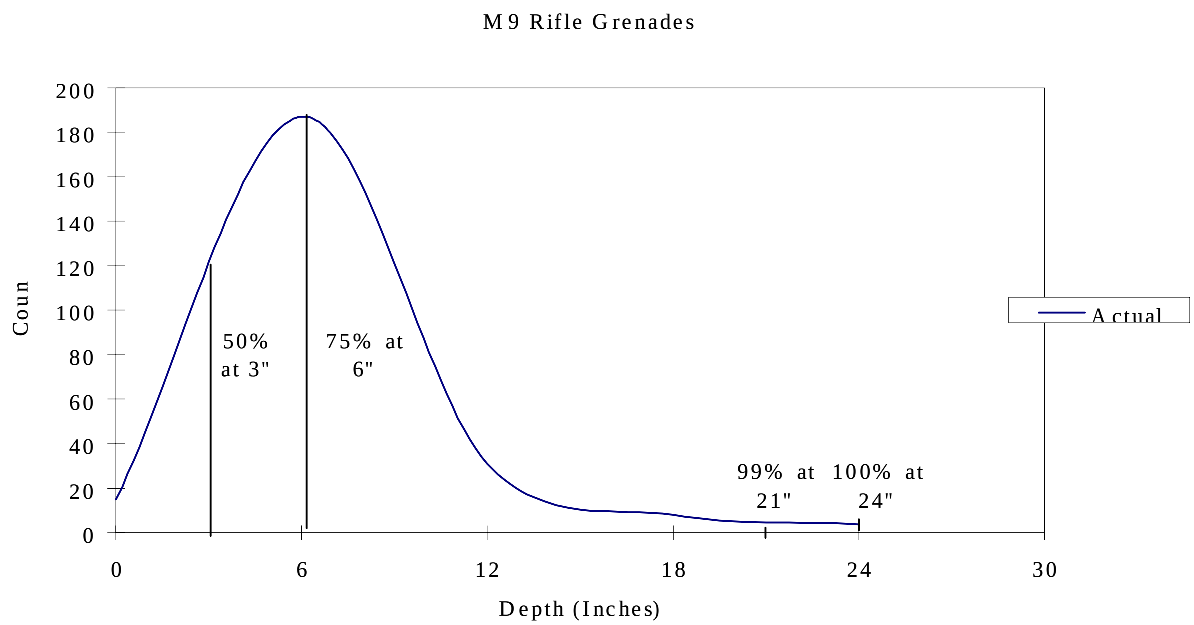


Figure 4: 35mm M73 Sub-cal Rocket

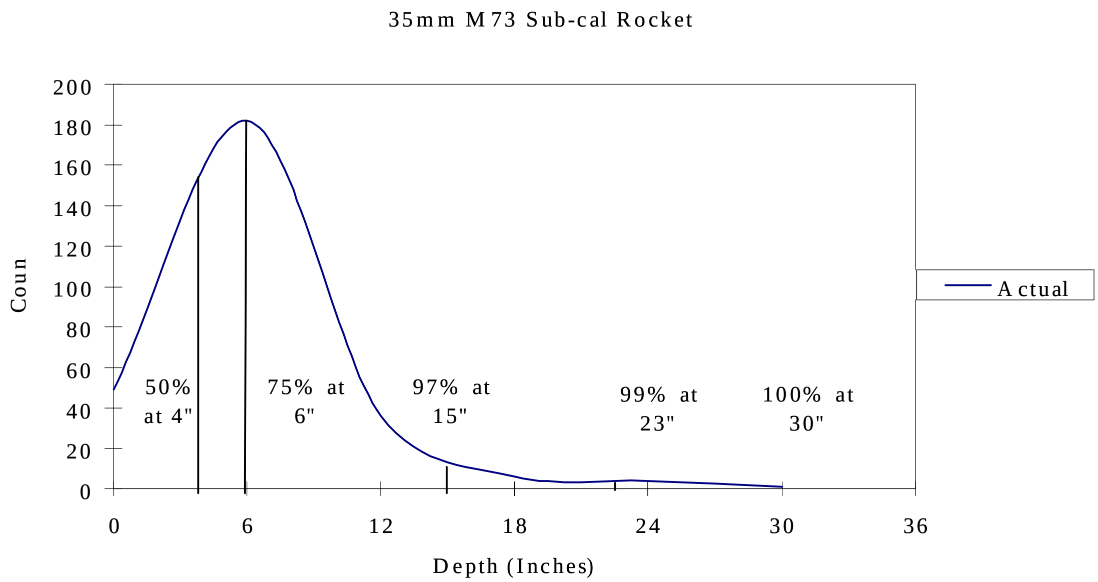
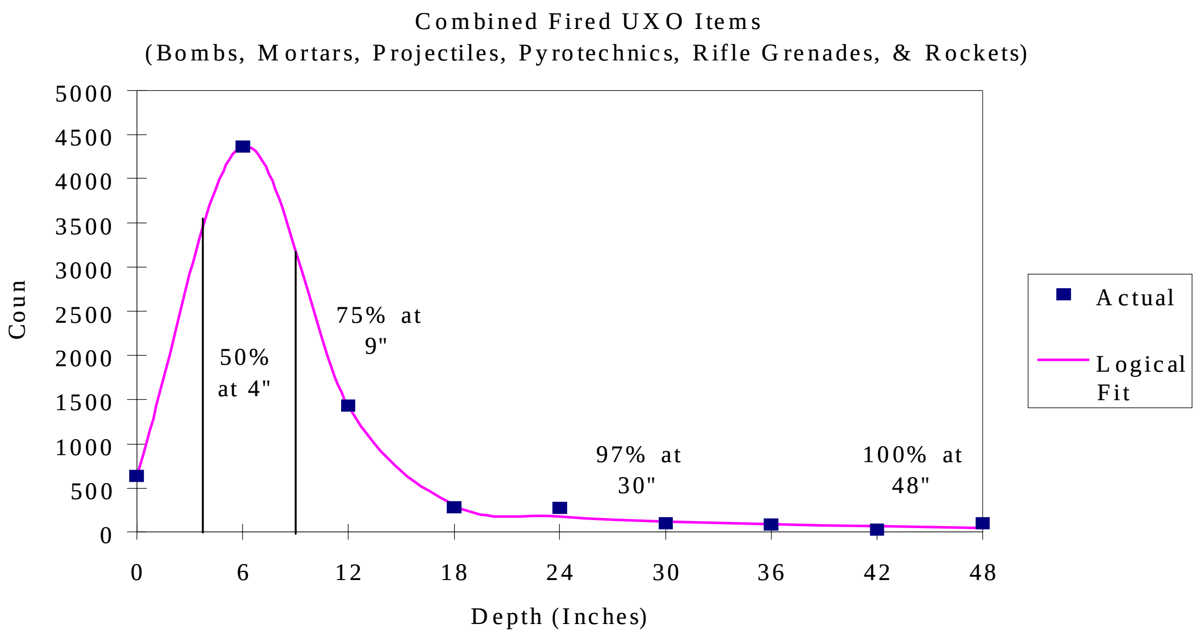


Figure 5: Combined Fired UXO Items Graph



Comparison of Recovered Maximum Depth and Mathematical Model Maximum Depth

The maximum penetration depth for all fired munitions can be calculated for all types of soil conditions. The actual conditions that the munition was fired under are unknown; therefore, several assumptions concerning those conditions must be made to calculate the depth. The assumptions used in the model result in a "worst case" scenario. Two of the assumptions that must be made are:

1. Striking Velocity – Velocity of munition upon impact with ground
2. Striking Angle – Angle of munition upon impact with ground

The assumptions for these two conditions are that the munition strikes the ground with a maximum muzzle velocity for the munition and a normal or perpendicular angle relative to the ground [3]. Since there are many factors that must or must not happen for a worst case scenario to occur, it is reasonable to assume that worst case scenarios rarely occur. However, with no way to determine the factors of an event that happened 50 years ago, a mathematical model using a worst case scenario is the best way to determine maximum depth penetration of a munition at this time.

The data from the UXO Recovery Database show that for most ordnance types the maximum recovery depth is much less than the maximum calculated depth. Although this holds true for most types of ordnance, there are a few types that have been found below the calculated maximum depth. Table 2 compares the maximum calculated depths and maximum recovery depths for several of the ordnance types. Table 2 gives the calculated maximum depth, actual recovered maximum depth, and percent difference between the two. Three of the shown ordnance types have negative percent differences. Although there is no exact explanation for this, several reasons are suggested, including:

1. Area where item was found has been filled or leveled with fill dirt
2. Actual depth was not measured correctly by excavator
3. Military personnel buried the item instead of firing it

Table 2: Comparison of Calculated and Recovered Maximum Depths

Ordnance Type	Max. Calcualted Depth (Inches)	Max. Recoverd Depth (Inches)	Percent Difference
Projectile, 37mm	95	30	68%
Projectile, 40mm	142	26	82%
Projectile, 57mm	66	36	45%
Projectile, 75mm	119	48	60%
Projectile, 105mm	212	48	77%
Projectile, 155mm	342	36	89%
Mortar, 3" Stokes	82	36	56%
Mortar, 61mm	26	36	-38%
Mortar, 81mm	65	48	26%
Rifle Grenades, M9	3	24	-700%
Rocket, 35mm	12	30	-150%

The maximum calculated depth for clay soil was used for each ordnance type. The clay soil depth was used since it has the deepest penetration of the soils. Although the database distinguishes the type of soil in which each UXO item was recovered, a soil type by soil type comparison was not made. The maximum recovered depth used was the deepest item recovered, without respect to soil type.

Although there is no way to predict a true penetration depth without knowing all relevant factors, the comparison between recovered depths and calculated maximum depths shows that, in most cases, the calculated depth is overestimated. The recovery depth of an item is not always the actual penetration depth, due to the three possible factors listed above and other factors such as frost upheaval and other natural occurrences. Therefore, a comparison between the historical depth and the calculated depth can be used to help predict a range of depths at which the UXO item can be expected to be found.

OE Risk, UXO Sweep Efficiency, Cleanup Cost Effectiveness, and UXO Detection Technology

When working at OE restoration projects, the probability that the public may come into contact with UXO can be predicted using OE risk calculations. OE risk uses statistical UXO densities and the number of people estimated to be at a site to predict the probability that the public will be exposed to UXO. Using the data from the UXO Recovery Depth Database to show that a specific percentage of a UXO item is historically found within a certain depth increases the confidence in the density estimate and increases the confidence in the risk calculations.

Sampling at OE projects is performed to provide statistical confidence in the location and extent of UXO at a site. A more accurate sample will provide a more accurate cost estimate and risk estimate. Using the database to determine historical natures of certain UXO items will assist in the development of more accurate sampling and statistics at UXO sites.

Historical data can also be used to determine the appropriate technology to use for optimum detection of the UXO at a site. Different types of detection tools have better efficiencies at different depths; therefore, the database can help select the best tool for a certain type of UXO. The improved detection capability will then lead to an increase in the effectiveness of the UXO sweep at the site.

Conclusion

In conclusion, the UXO Recovery Depth Database has been developed to aid in making decisions concerning OE restoration projects. The data can be used to compare actual recovery depths and calculated maximum depths to predict ranges of recovery depths for UXO items. Statistical UXO densities used to make OE risk predictions and OE sampling used to provide cost estimates can be improved by using historical data contained in the database. Sweep efficiencies can also be improved, since the best detection tool can be identified.

REFERENCES

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3. Crull, Dr. Michelle; Taylor, Linda; and Tipton, John. Estimating Ordnance Penetration into Earth; UXO Forum 99; Atlanta, GA; May 1999.